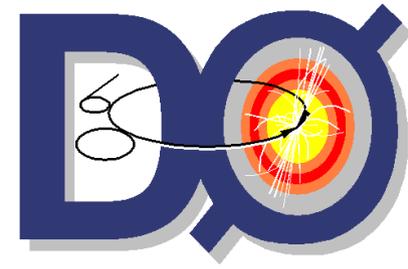




Spectroscopy at the Tevatron



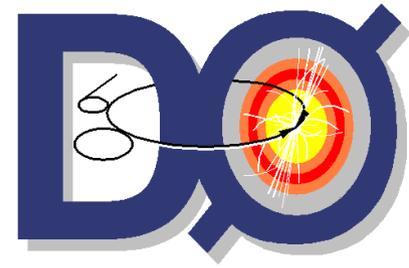
Martin Heck
(KIT)

on behalf of the CDF and D0 collaborations

Beauty 2009



Motivation and Overview



- Discovery of charmonium-like states with non-fitting properties (XYZ)
- Exotic models as explanation
- Figured, we could contribute, too

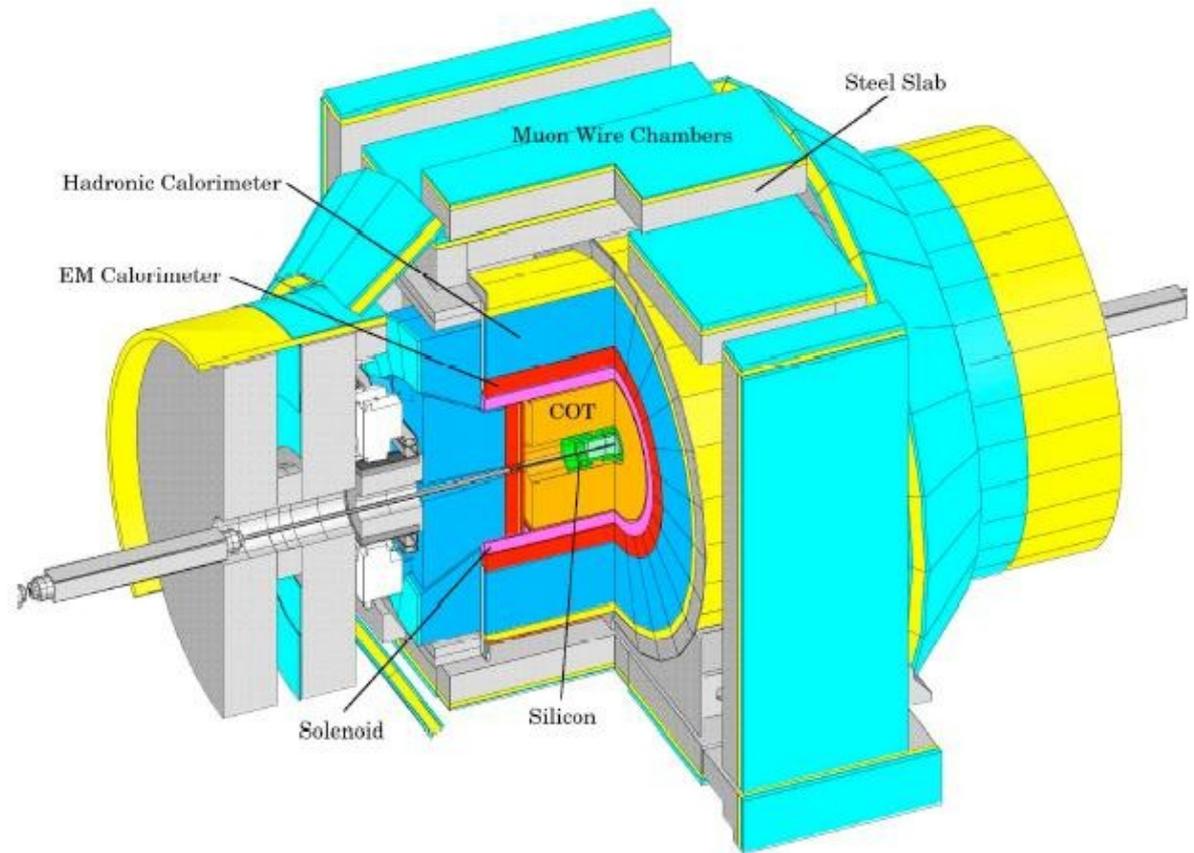
Tevatron contributions

- $X(3872)$
- New resonance decaying into $J/\psi \phi$



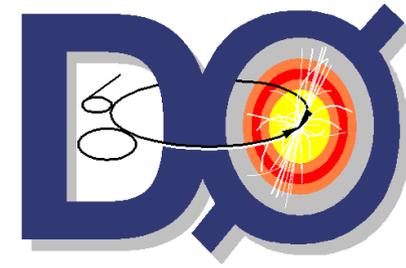
The Experiment

- 1.96 TeV proton-antiproton collider with two interaction points for D0 and CDF
- Almost 7 fb^{-1} delivered
- More detailed information, see talk of Michal Kreps yesterday

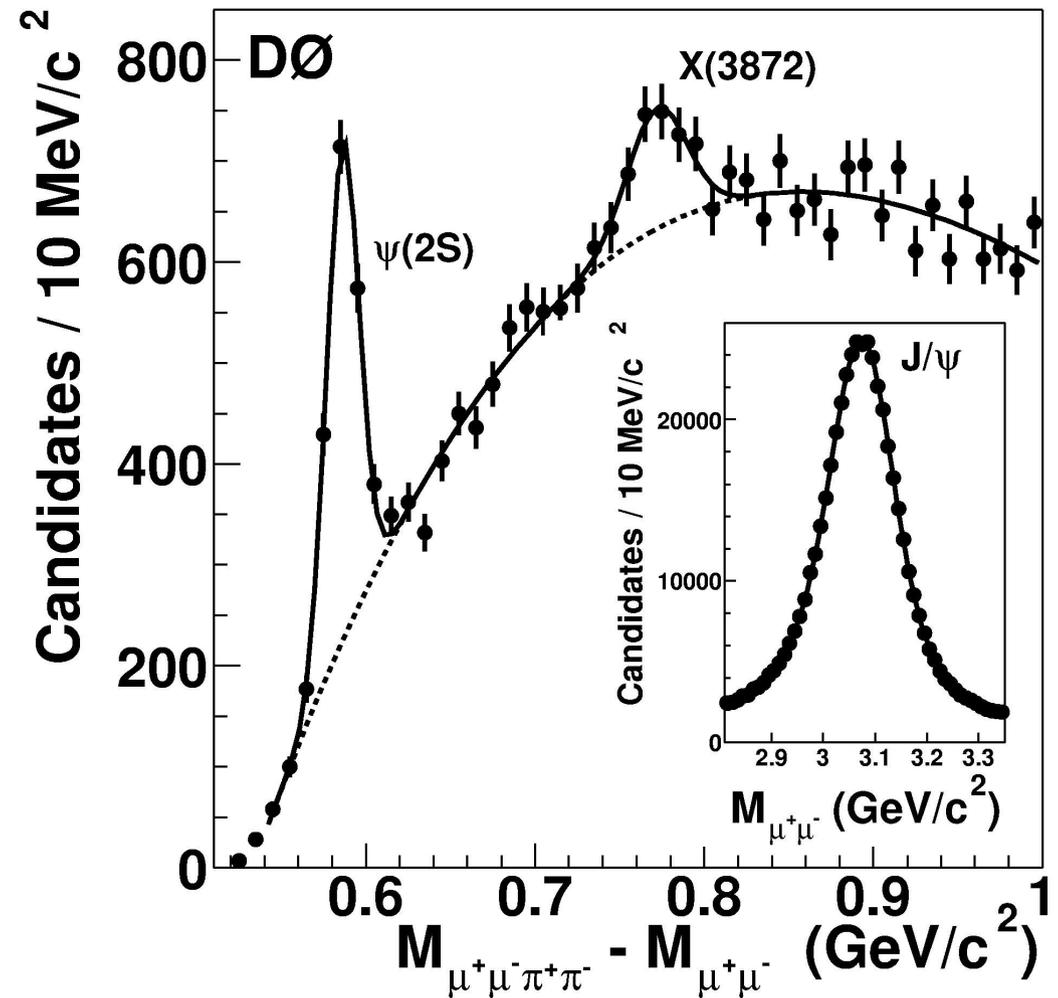




X(3872) History

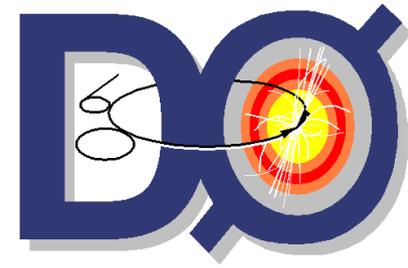


- Discovery by Belle in 2003
- CDF and DØ both have seen the X(3872) resonance in decays to $J/\psi \pi^+ \pi^-$ and confirmed Belle in 2004





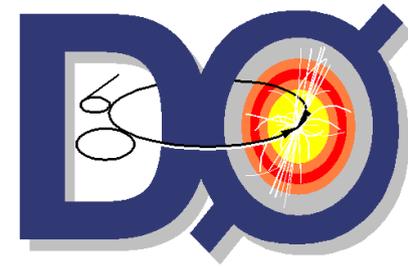
X(3872) History



- CDF quantum number study revealed a 1^{++} or 2^{-+} state
- The X(3872) doesn't fit into the charmonium spectrum very well due to quantum numbers and mass (not impossible)
- Exotic explanations most likely



Mass and Width as Tests

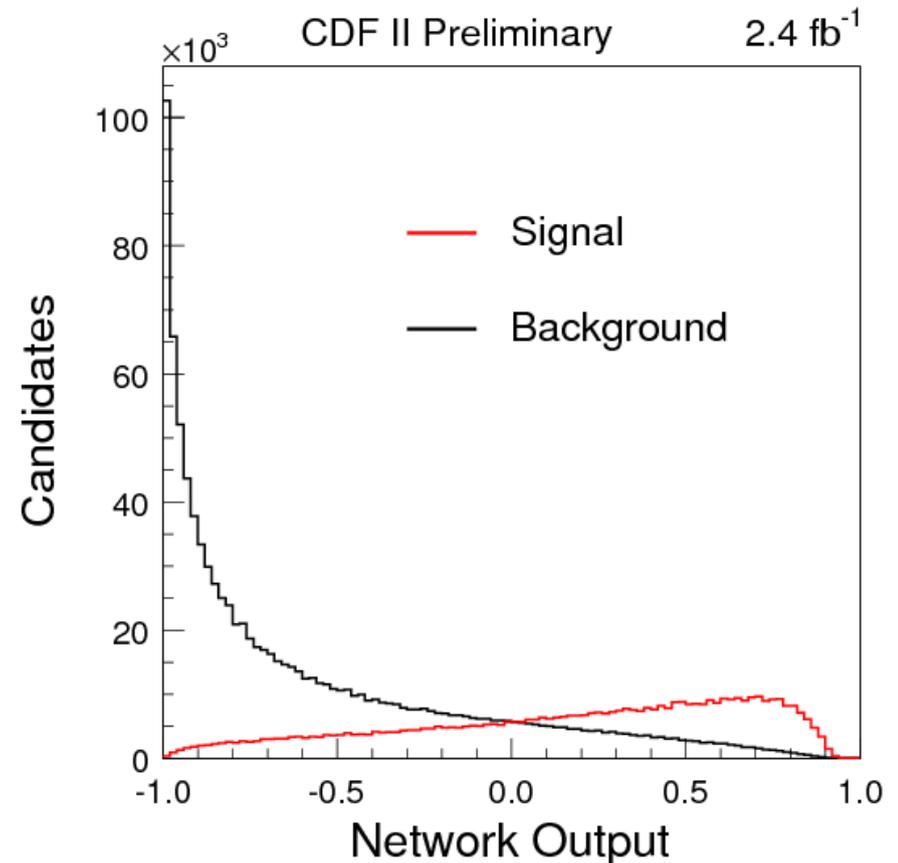


- At least two exotic models can be tested with mass and width measurements
 - **Four-quark state** (model of Maiani et al.)
prediction: $X(3872)$ contains two slightly differing mass states ($\sim 8 \text{ MeV}/c^2$)
Phys. Rev. D 71, 014028 (2005)
 - **Molecular state** composed of D^0 and D^{0*} mesons
prediction: $X(3872)$ mass slightly below the sum of the corresponding meson masses
Phys. Lett. B 590, 209 (2004)
Phys. Lett. B 588, 189 (2004)



X(3872) Analysis

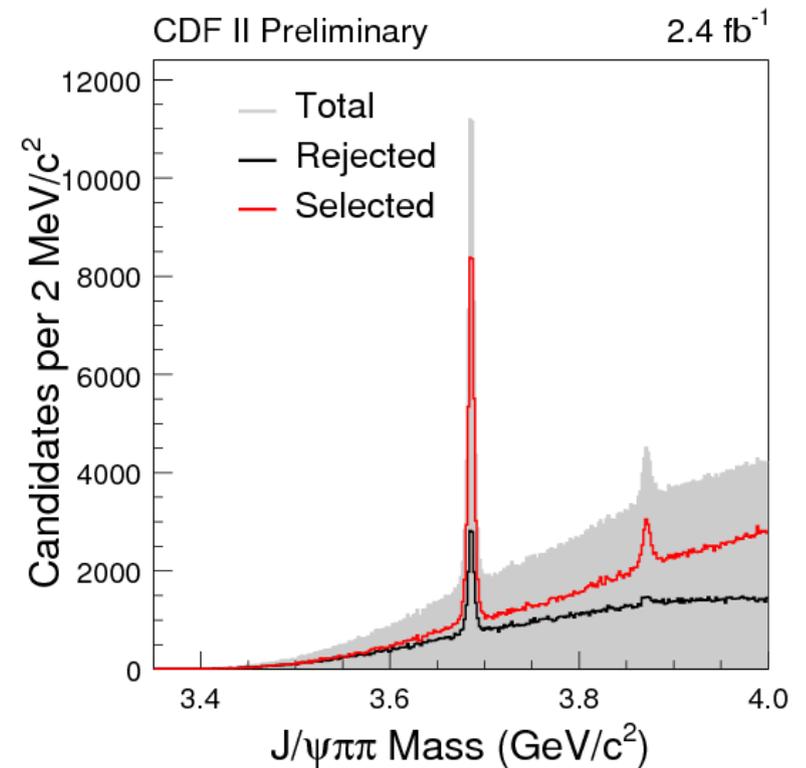
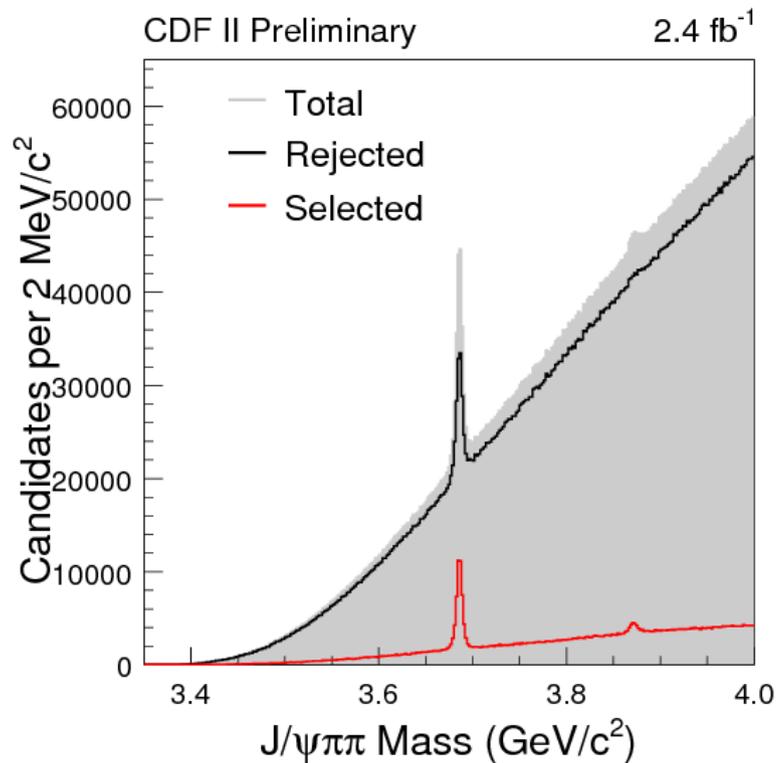
- Multivariate technique with neural network to separate signal/bkg
- Training samples
 - MC for signal
 - Mass sideband for bkg
- Most important quantities
 - Q value, transverse pion momenta, kinematic fit quality, muon identification





X Final Selection

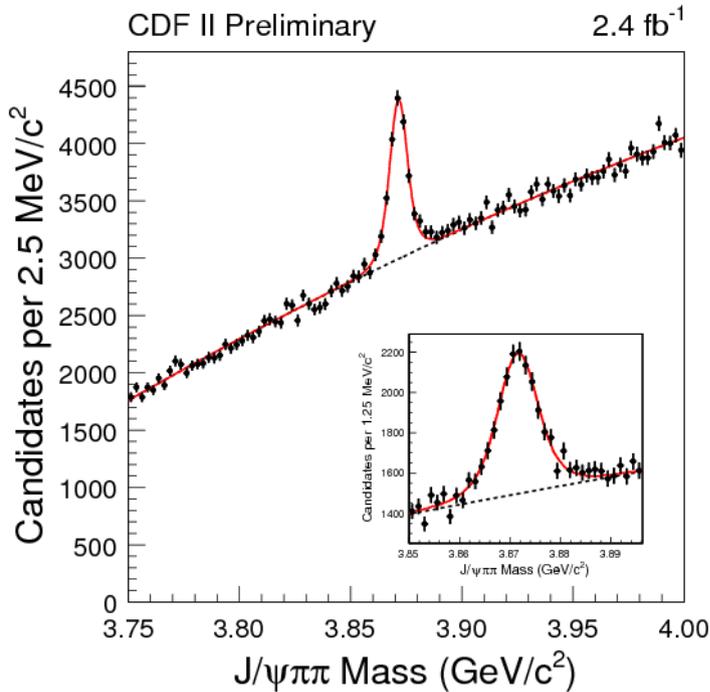
- Cut on Neural Network Output
- Number of candidates ≤ 3 per event



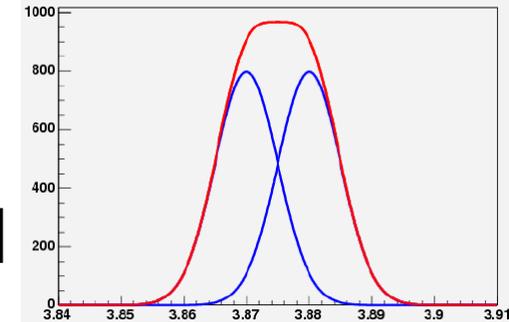
Select around 34500 $\Psi(2S)$ and 6000 X(3872)



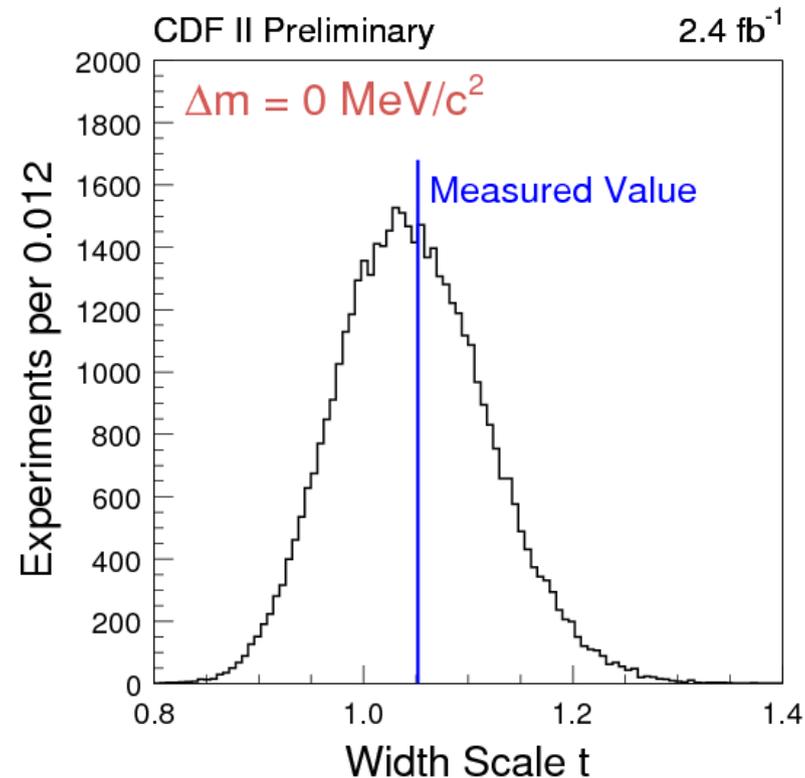
X(3872) Shape



- Signal shape by Voigt function, with width fixed apart from scale factor



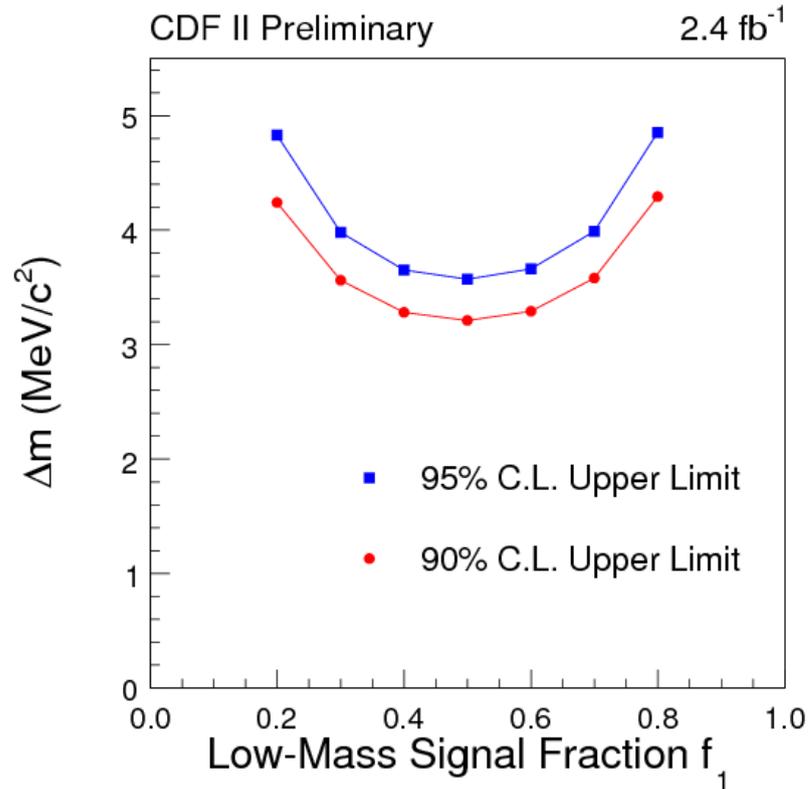
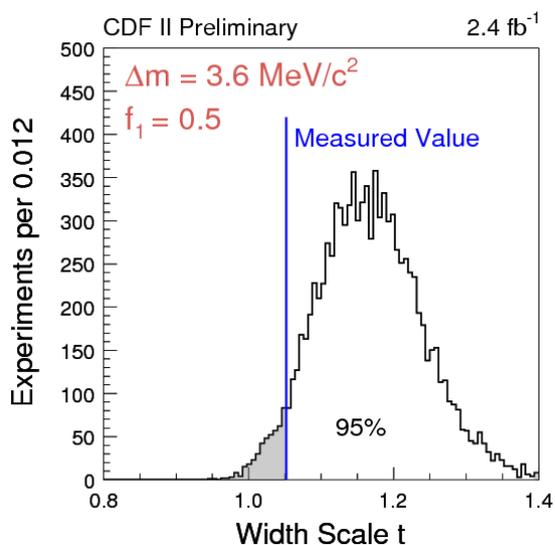
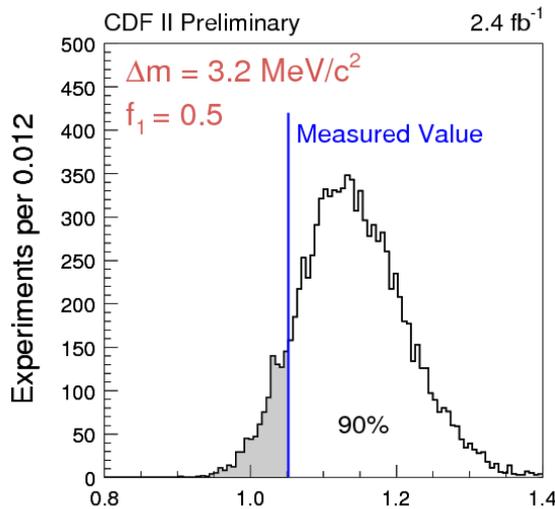
- Comparison with Toy MC of single state
==> limit on max Δm





Maximum Mass Difference

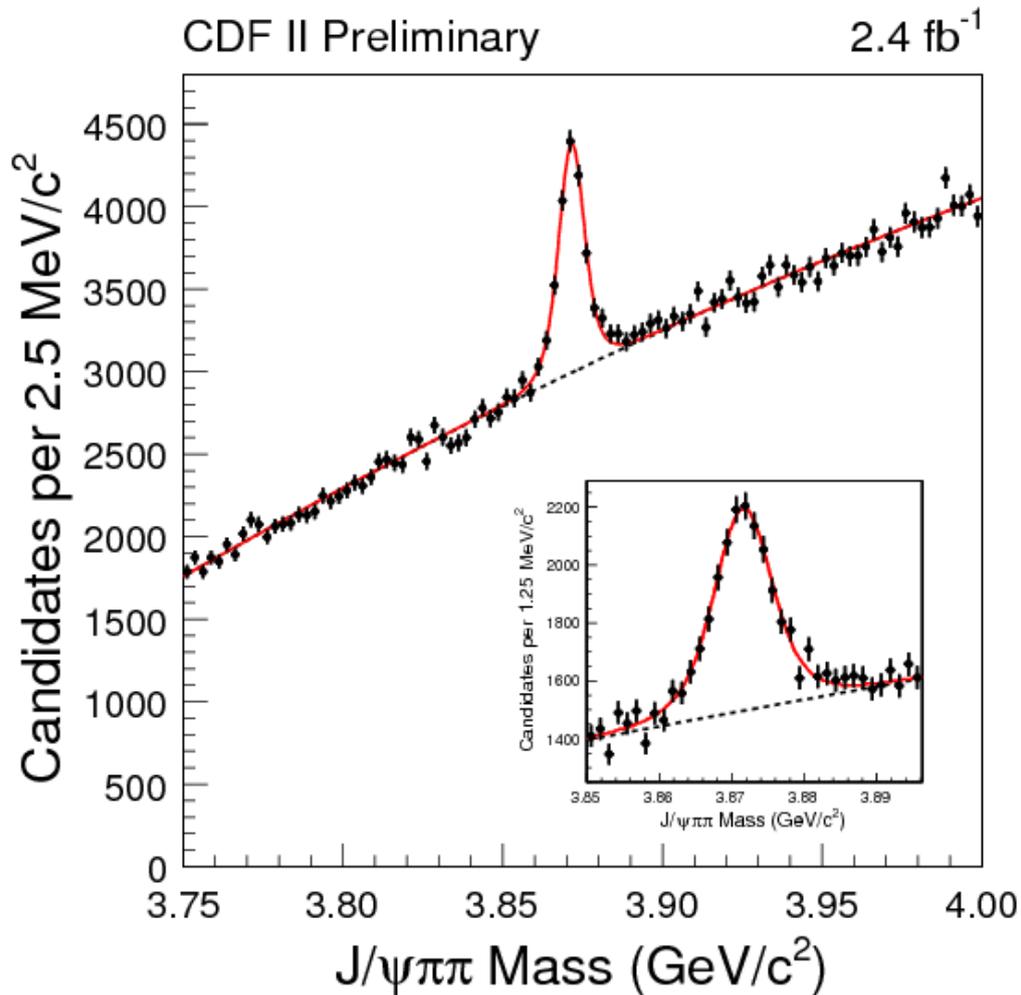
Toy MC with various widths to determine limit



4-quark hypothesis (Maiani et al.):
 $\Delta m = 8 \pm 3 \text{ MeV}/c^2$



X(3872) Mass

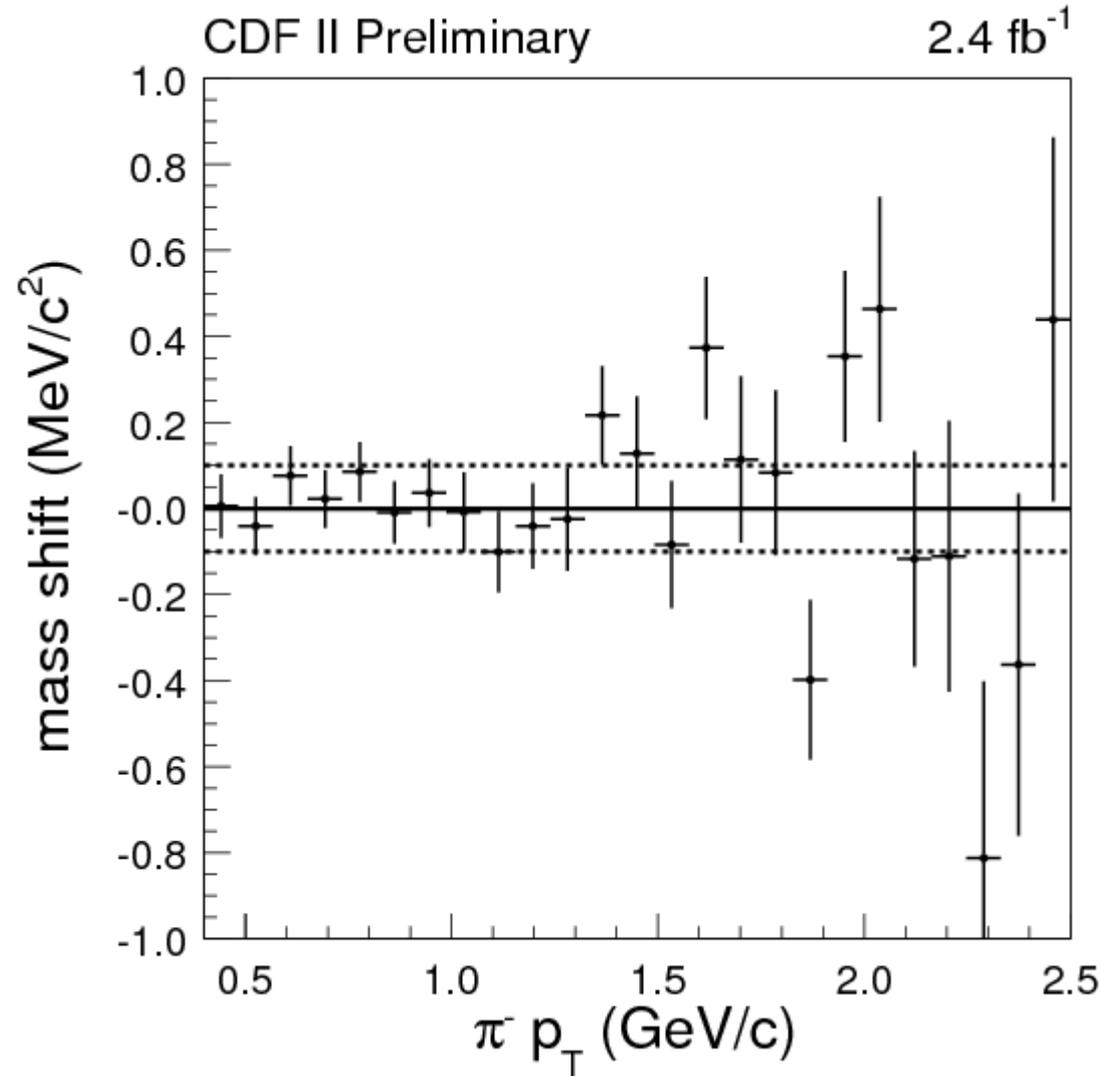


- Unbinned maximum likelihood fit
- Voigt function (nat. width fixed to BABAR/Belle result, resolution fixed to MC; apart from scale factor)
- BKG with second order polynomial



X systematics

- Mass dependency on transversal momentum of child particles for the $\Psi(2S)$
 - $100 \text{ MeV}/c^2$
- Multiplied with the Q value ratio for the X(3872)

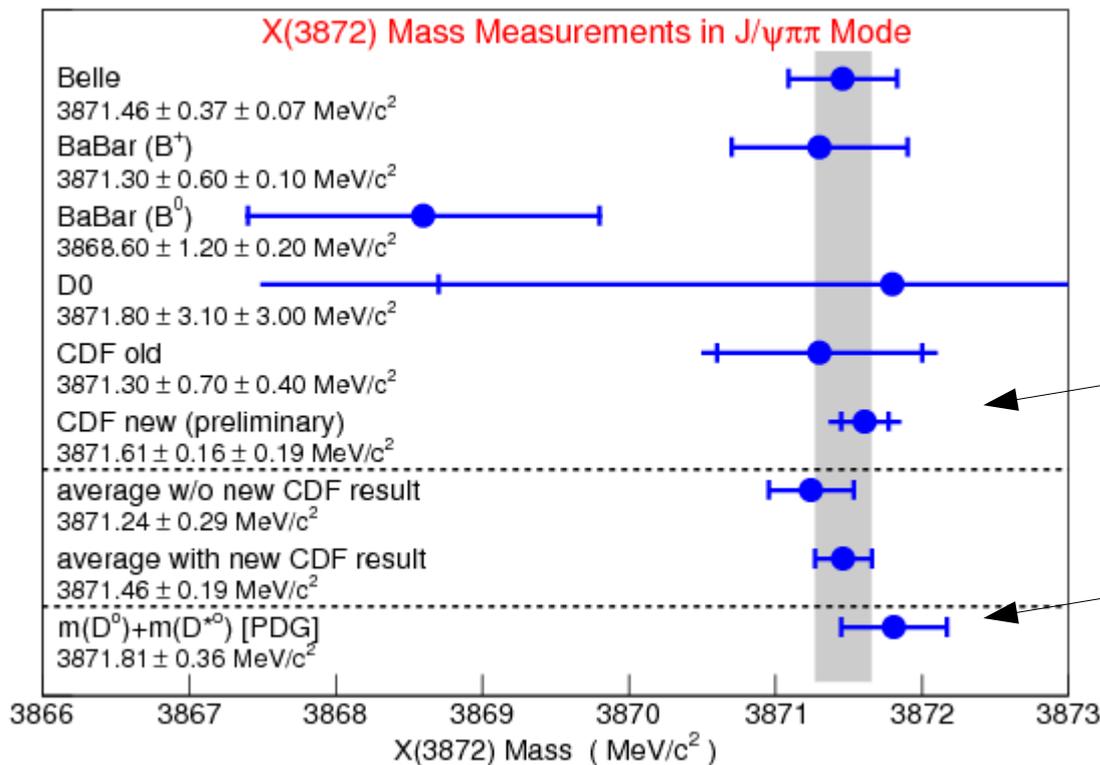




- Momentum scale uncertainty estimated from

$$\Psi(2S) \rightarrow J/\Psi \pi^+ \pi^-$$

- $m(X(3872)) = 3871.16 \pm 0.16$ (stat) ± 0.19 (sys) MeV/c^2



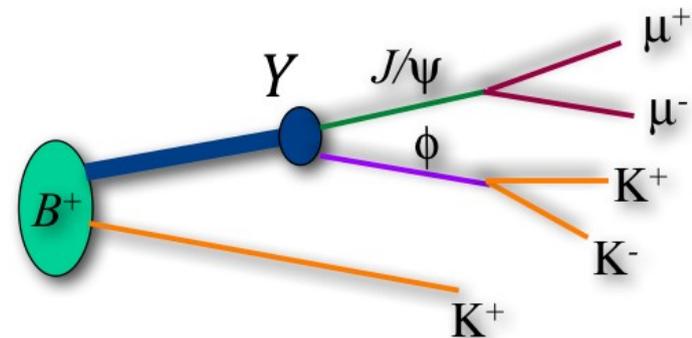
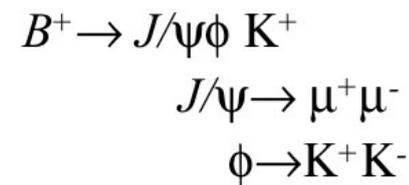
Most precise mass measurement

Molecular model still possible



Y(4140)

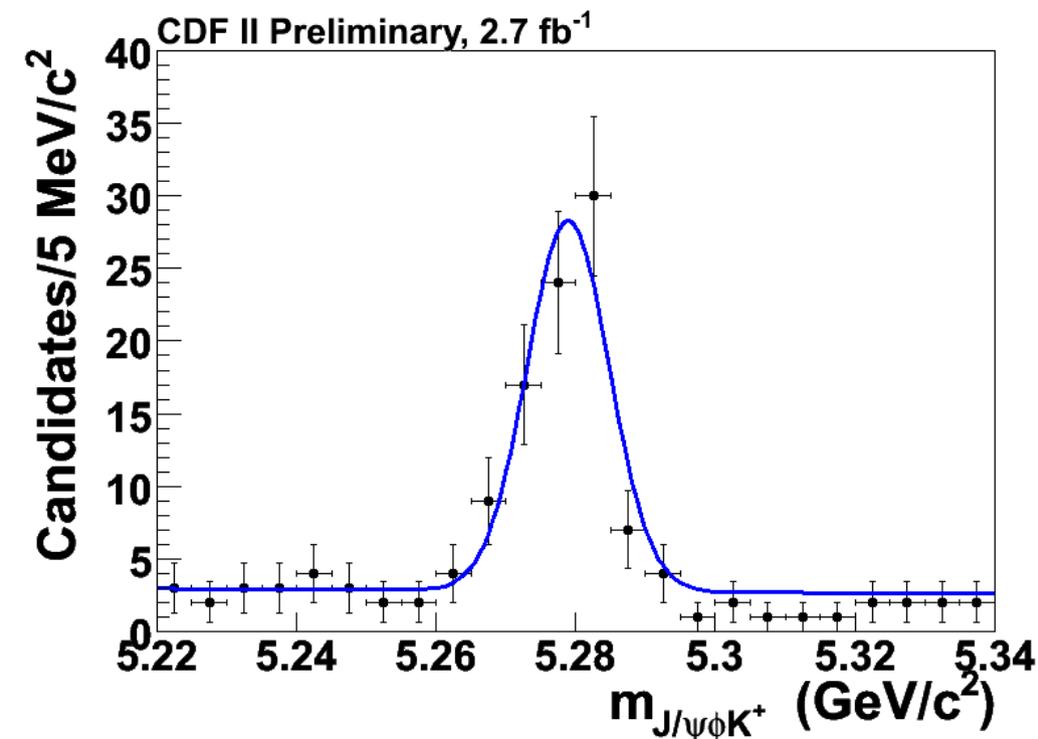
- $J/\psi \phi$ good channel for exotic meson search
 - Two vector mesons
- Search near $J/\psi \phi$ threshold motivated by closeness of Y(3930) to $J/\psi \omega$ threshold
- Strong bkg reduction by using exclusive B^+ decays to $J/\psi \phi K^+$





$B^+ \rightarrow J/\psi \phi K^+$ selection

- $J/\psi \rightarrow \mu^+ \mu^-$, $\phi \rightarrow K^+ K^-$, additional kaon track
- Decay length and particle identification to separate the signal from bkg

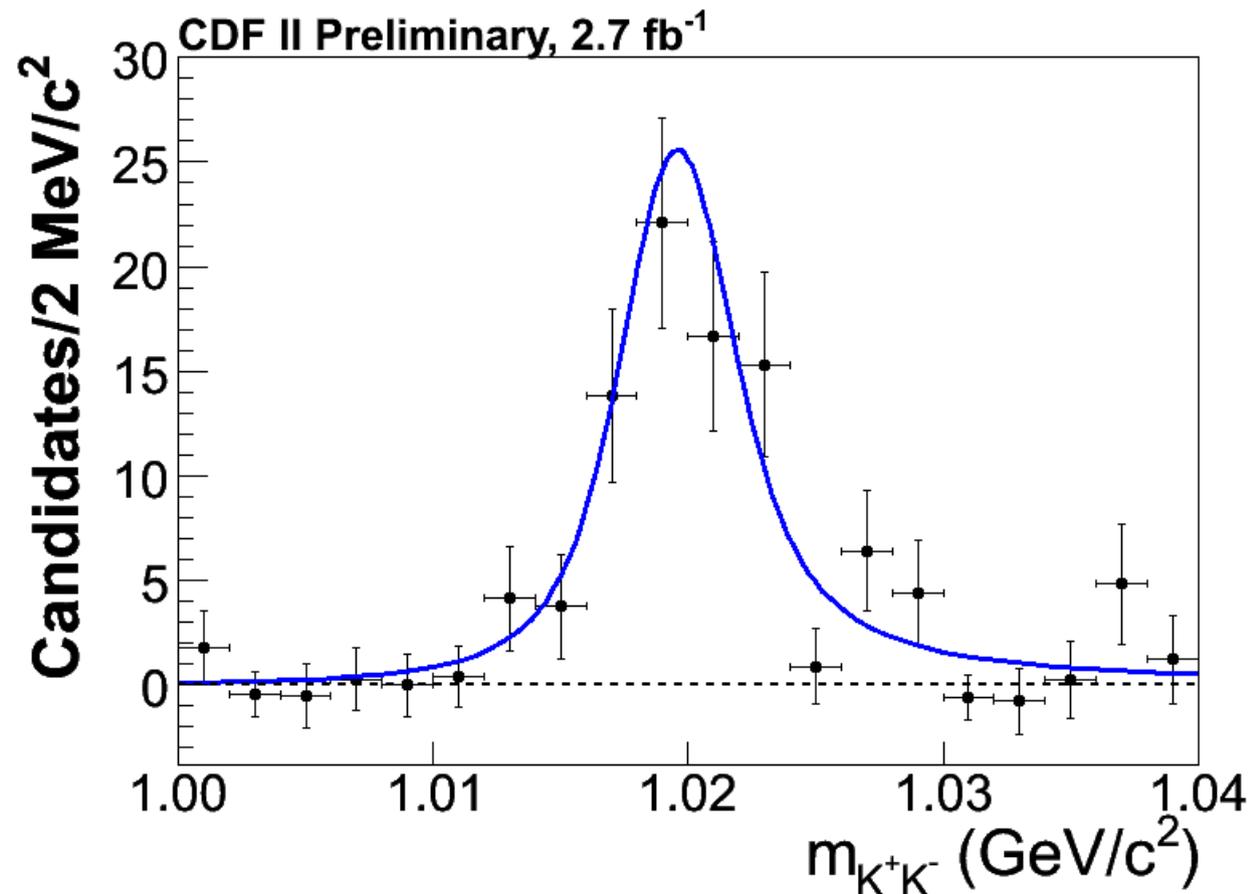


- Signal of $75 \pm 10 B^+$ mesons
- Select candidates $\pm 3 \sigma$ (17.7 MeV/c²) around B^+ peak



ϕ mass spectrum

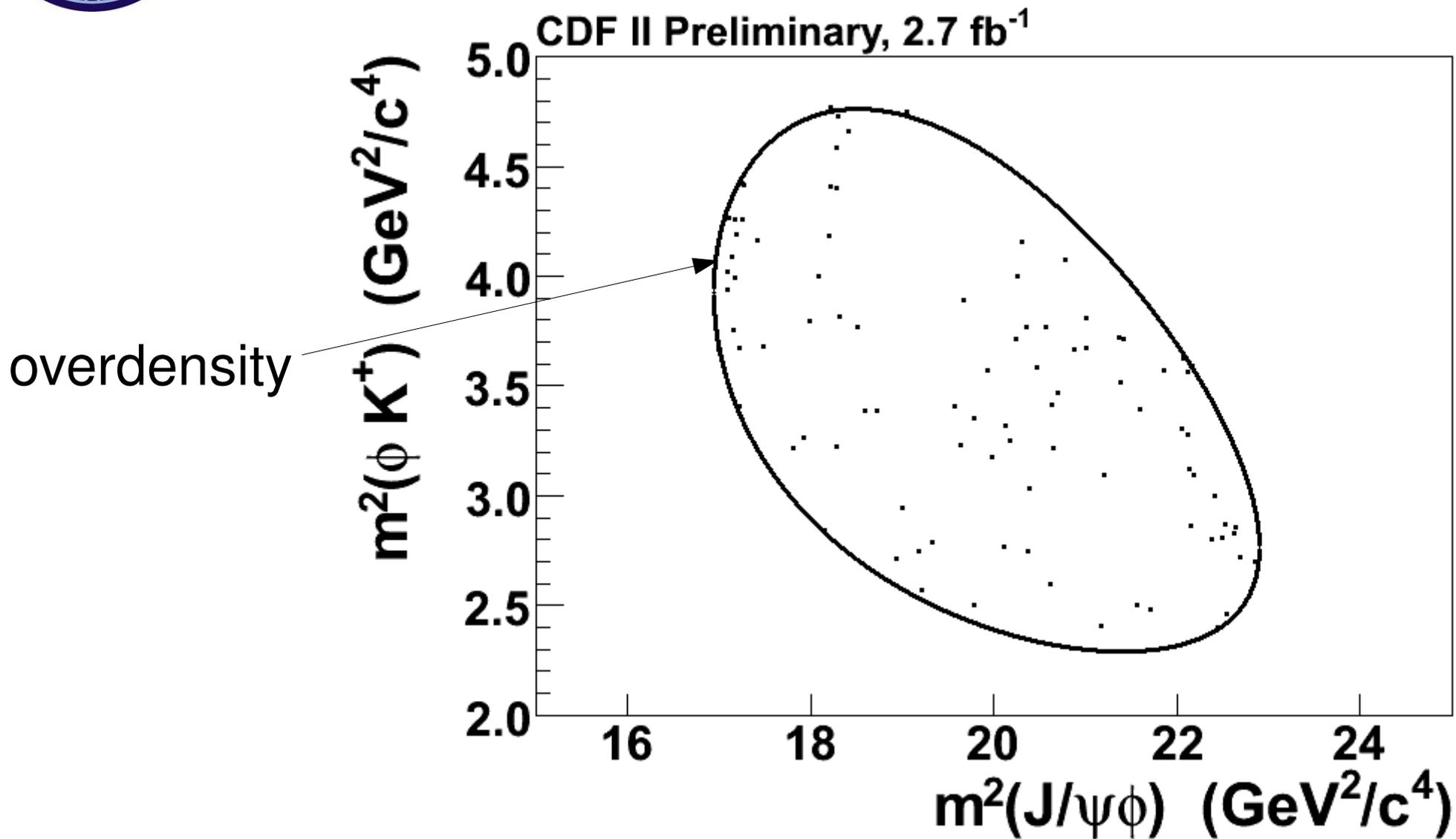
- B^+ sideband subtracted without ϕ mass window requirement
- P-wave relativistic BW with Gaussian resolution from MC



$\Rightarrow B^+ \rightarrow J/\psi K^+ K^+ K^-$ final state well described as $J/\psi \phi K^+$



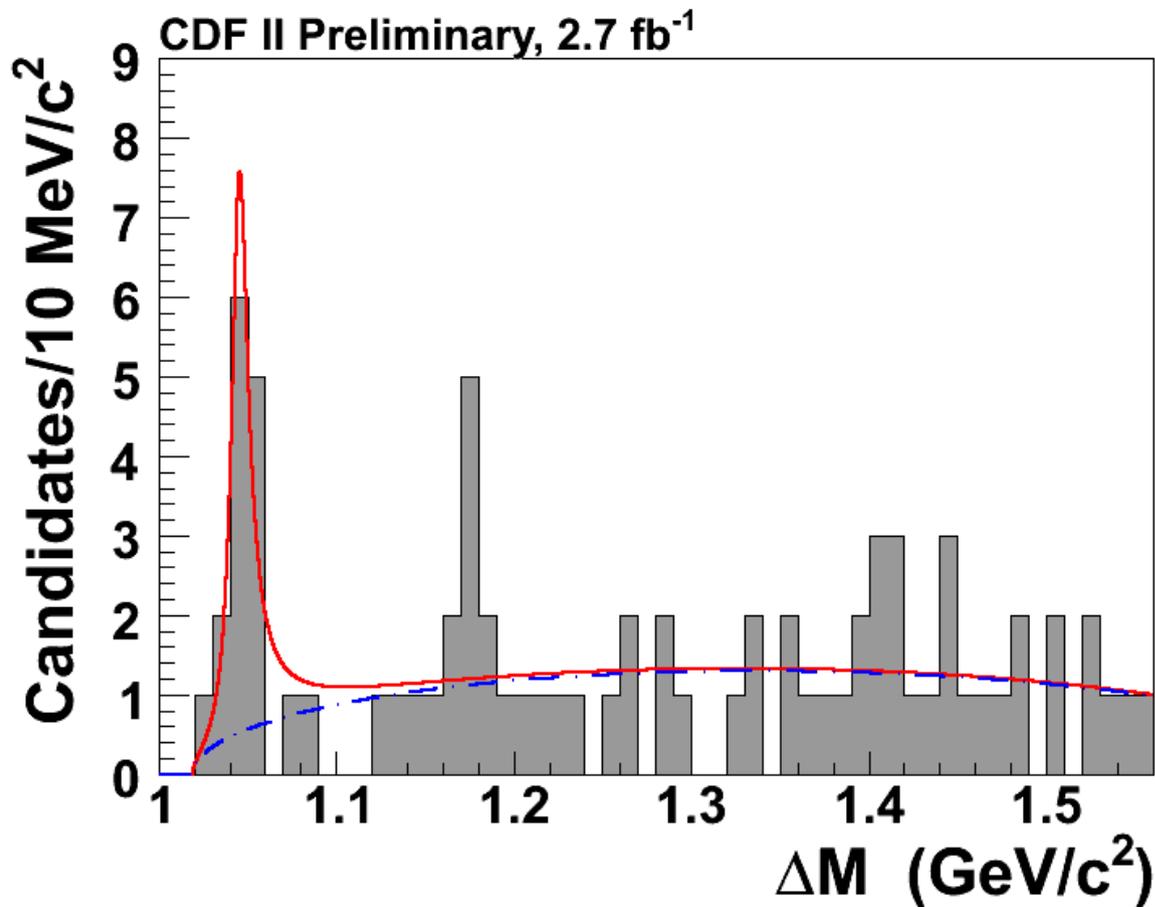
Dalitz Plot





$J/\psi \phi$ mass spectrum

- $\Delta M = m(\mu^+ \mu^- K^+ K^-) - m(\mu^+ \mu^-)$
- 73 events with $\Delta M < 1.56 \text{ GeV}/c^2$

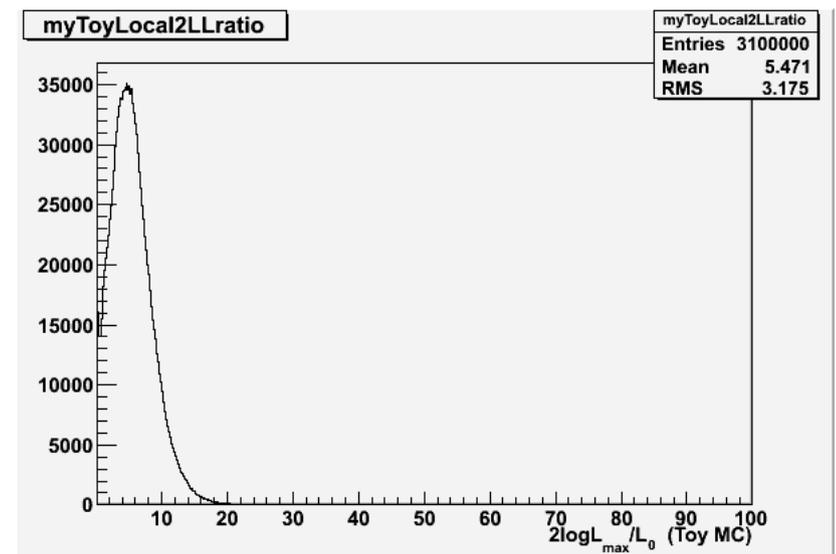


- Unbinned likelihood fit
- Signal:
Relativistic BW
convoluted with Gaussian
(resolution fixed to
 $1.7 \text{ MeV}/c^2$ from MC)
- Bkg
3 body phase space
- 14 ± 5 signal events



Significance

- Calculate $-2 \log$ -likelihood ratio
- Modelling combinatorial bkg in B^+ mass window separately as flat spectrum in addition to 3-body phase space reduces that value
- p value study for similar signal anywhere in the mass window
→ **significance of 3.8σ**





Mass

- Systematic uncertainties from varying the fit model
- Using world average mass of J/ψ meson
- $M = 4143.0 \pm 2.9$ (stat) ± 1.2 (sys) MeV/c²
- $\Gamma = 11.7^{+8.3}_{-5.0}$ (stat) ± 3.7 (sys) MeV/c²



Summary X

- Mass shape study
 - Not revealing evidence for 2-state hypothesis
- Mass measurement
 - Still allows molecular bound state consisting of $D^0 D^{0*}$ mesons
 - Mass uncertainty about as good as uncertainty for 2 times D^0 mass



Summary Y

- Evidence (3.8σ) for an exotic charmonium-like state

$$Y(4140) \rightarrow J/\psi \phi$$

$$- M = 4143.0 \pm 2.9 \text{ (stat)} \pm 1.2 \text{ (sys)} \text{ MeV}/c^2$$

$$- \Gamma = 11.7^{+8.3}_{-5.0} \text{ (stat)} \pm 3.7 \text{ (sys)} \text{ MeV}/c^2$$